An energy perspective on economic activities

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Chapter 7

Household energy requirements in the year 2015

The previous chapters investigated the energy intensities of the production sectors and household energy requirements in the year 1990 and the preceding two decades. The investigations showed that, in the 70s and 80s, the improvements in energy efficiency were offset by an increase in household consumption. This chapter investigates the possible development in household energy requirements during the 25 years period 1990-2015. The main part of this chapter concerns a further reduction in energy requirements and the corresponding CO_2 emissions by implementing energy efficiency enhancing technologies in production and consumption activities (sections 7.1 and 7.2). These investigations are carried out with the input-output method. Section 7.3 shows how the EAP program can be used for calculations concerning the reduction of energy reuirements and CO_2 emissions.

7.1 METHOD

Three main options for reducing energy requirements of households are:

1) improving the energy efficiency of production sectors and households
2) changing the production structure of the economy
3) changing volume and pattern of household consumption.

This can be easily concluded from formula (3.29) in which the direct energy intensity vector **d** corresponds to energy efficiency, the technological matrix **A** corresponds to the production structure, and the household consumption vector **y** corresponds to the consumption pattern. In a preliminary study, Wilting and Biesiot (1993) already presented a sensitivity analysis concerning the effect of changes in the elements of the technological matrix and the direct energy intensities on energy intensities of production sectors and household energy requirements. Appendix 7.A gives an overview of this analysis. This chapter investigates one of the options mentioned: the improvements in energy efficiency of production and consumption sectors assuming unchanged production structure and consumption patterns.

According to figure 1.2, three groups of actors are involved in household energy requirements: the households, the non-energy production sectors and the energy supply system. Not all actors have the same share in household energy requirements. So, a first approach concerning the reduction of household energy requirements is the identification of actors with a high share in household energy requirements. This means that household energy requirements are allocated to the sectors in which energy use actually takes place. Direct energy requirements of households are attributed to households and the energy supply system. The share of the separate production sectors in the energy requirements of households, **E**, is determined with formula (3.30). The share, $\mathbf{c_j}$, of sector **j** is:

$$c_j = \frac{E_j}{E} \text{ , with } E_j = d_j\, x_j^h \tag{7.1}$$

with $\mathbf{d_j}$ the direct energy intensity of sector **j** and $\mathbf{x_j^h}$ the total production necessary for household consumption produced by sector **j**. Similarly, the shares of the households and the energy supply system in total household energy requirements can be calculated.

The allocation of household energy requirements to the separate actors identifies sectors with a large share in household energy requirements. These sectors deserve the most attention in energy policy. However, chapter 6 showed that for some sectors the decrease in energy intensity was larger than for other sectors. So, some sectors achieved already a reasonable decline in energy intensity. In other sectors hardly any attention has been paid to energy conservation. Therefore, the energy conservation potential is not the same for all sectors.

The next step is the implementation of existing knowledge on technical energy conservation potentials in the input-output model to determine the potential savings. Knowledge about energy conservation potentials is derived from studies aimed at the possibilities for decreasing direct energy use in production and consumption sectors. The potential savings in household energy requirements based on savings in sector **j** are:

$$S_j = t_j\, E_j \tag{7.2}$$

with $\mathbf{t_j}$ the technical energy conservation potential of sector **j**. So, the effect of conservation measures in a certain sector on household energy requirements depends on the share of that sector in household energy requirements and the technical energy conservation potential of that sector.

The energy requirements of the energy supply system are derived from the energy demand of production and consumption sectors. Thus, energy conservation measures in the households and the non-energy production sectors bring about savings in the energy supply system. Beside these savings, energy efficiency improvements in the energy sectors play a role.

The financial and energy costs required by the conservation measures are not taken into account in the present calculations. The additional energy costs for the investments directed at the energy conservation measures are relatively small (Noorman, 1995).

7.2 PREDICTED ENERGY REQUIREMENTS

Sectors with a high effect on household energy requirements are attractive in bringing about energy conservation and CO_2 emission reduction concerning household consumption. These sectors are characterized by either a high technical energy conservation potential or a large share in household energy requirements. This section determines the share of the separate sectors in household energy requirements. Table 7.1 gives a breakdown of the 1990 household energy requirements in sectors in which the energy use actually takes place[1].

The production of goods and services in the production sectors requires more energy than the households use directly. Indirect energy requirements have a heterogeneous character. However, the main part of indirect household energy requirements occurs in a small number of production sectors. Sectors with a high share in indirect household energy requirements either have a high direct energy intensity or a high production needed for household consumption. E.g. the share of sector 26 (the chemical basic products industry) in energy requirements amounts to about 11% due to a high direct energy intensity. Other sectors with a high direct energy intensity are sector 30 (basic metal industry) and sector 2 (fishing). Conversely, sector 41 (trade) has a high share in household energy requirements due to a high production needed for household consumption. Table 7.2 gives the ranking of sectors in terms of direct energy intensity, production for household consumption and share in household energy requirements. The percentage values given are cumulative.

[1] Since the ERE values in the model used in this chapter are slightly different from the ERE values in chapters 5 and 6, direct energy intensities in table 7.1 do not exactly match those in table 5.1. Similarly, household energy requirements in table 7.1 do not exactly match with in table 5.9.

Table 7.1 Share in household energy requirements (E in PJ and %) per sector. The direct primary energy intensity (d in MJ/Dfl) and total production for household consumption (x^h in billion Dfl and %) for production sectors are also shown.

sector		d MJ/Dfl	x^h 10^9 Dfl	%	E PJ	%
1	agriculture, horticulture and forestry	4.6	19.9	3.5	91.6	5.3
2	fishing	15.0	.5	.1	8.2	.5
3	crude oil and natural gas production	.0	11.7	2.0	.0	.0
4	other mining and quarrying	1.3	.8	.1	1.0	.1
5	slaughtering and meat-processing ind.	.4	7.1	1.2	2.7	.2
6	manufacture of dairy products	1.5	6.6	1.1	9.8	.6
7	processing of fish, fruit and vegetables	1.1	2.0	.4	2.3	.1
8	grain-processing industry	1.1	5.4	.9	5.9	.3
9	sugar industry	7.5	1.0	.2	7.3	.4
10	flour-processing industry	.9	4.0	.7	3.4	.2
11	manufacture of cocoa and chocolate	1.1	1.5	.3	1.7	.1
12	manufacture of margarine, starch, etc.	2.2	6.5	1.1	14.3	.8
13	beverage industry	1.5	3.7	.6	5.5	.3
14	tobacco-processing industry	.5	1.1	.2	.5	.0
15	wool industry	1.8	.5	.1	.8	.0
16	cotton industry	2.6	3.1	.5	8.1	.5
17	knitting and hosiery industry	1.0	3.1	.5	3.2	.2
18	textiles industry	1.3	3.2	.6	4.2	.2
19	clothing industry	.3	4.7	.8	1.3	.1
20	leather, footwear and other leatherware	.6	2.8	.5	1.7	.1
21	wood and furniture industry	.6	7.7	1.4	4.3	.3
22	paper and cardboard industry	9.6	4.8	.8	46.0	2.7
23	paperware and corrugated cardboard ind.	.9	3.4	.6	3.0	.2
24	printing, publishing and related ind.	.4	15.2	2.7	6.7	.4
25	petroleum industry	.0	5.6	1.0	.0	.0
26	chemical basic products industry	20.4	9.4	1.6	191.3	11.1
27	chemical final products industry	1.2	8.7	1.5	10.8	.6
28	rubber and plastic-processing industry	1.7	7.5	1.3	12.9	.7
29	manufacture of building materials, etc.	5.2	5.0	.9	26.3	1.5
30	basic metal industry	18.6	6.0	1.1	112.6	6.5
31	manufacture of metal products	.8	11.7	2.1	9.3	.5
32	machinery	.5	9.8	1.7	4.6	.3
33	electrotechnical industry	.8	17.4	3.0	14.8	.9
34	automobile industry	.6	9.9	1.7	5.6	.3
35	manufacture of transport equipment	.3	3.1	.5	1.0	.1
36	manufacture of instr. and optical goods	.4	3.8	.7	1.5	.1
37	electricity generation	.0	8.1	1.4	.0	.0
38	gas distribution	.0	6.9	1.2	.0	.0
39	water supply	2.9	1.8	.3	5.0	.3
40	construction and installation	.5	31.0	5.4	15.6	.9
41	wholesale trade and retail trade	.8	72.1	12.6	59.2	3.4
42	hotels, restaurants, cafes etc.	1.9	12.8	2.2	23.7	1.4
43	repair of consumer goods	.9	7.9	1.4	6.9	.4
44	sea and air transport	3.8	2.3	.4	8.7	.5

Table 7.1 (continued)

sector	d MJ/Dfl	x^h 10^9 Dfl	%	E PJ	%
45 other transport storage	4.8	8.8	1.5	42.0	2.4
46 communication	.6	9.0	1.6	5.3	.3
47 banking	.2	3.0	.5	.6	.0
48 insurance	.2	11.0	1.9	2.4	.1
49 exploitation of and trade in real estate	.1	50.2	8.8	3.9	.2
50 business services etc.	.7	58.4	10.2	38.1	2.2
51 government: civilian	.8	3.9	.7	3.2	.2
52 government: military	.7	.2	.0	.1	.0
53 government: education	1.1	1.1	.2	1.1	.1
54 social services etc.	1.6	16.1	2.8	25.3	1.5
55 health and veterinary services	.8	32.9	5.7	27.6	1.6
56 culture, sports and recreational services	1.4	10.4	1.8	14.4	.8
57 other services	1.4	6.2	1.1	8.5	.5
total production sectors		572.2	100.0	915.8	53.1
total households				810.3	46.9
total				1726.1	100.0

Table 7.2 Ranking of sectors in terms of direct energy intensity (d), total household production (x^h) and share in household energy requirements (E). The percentages are also given cumulatively.

rank	d		x^h			E		
	sector	MJ/Dfl	sector	%	cum	sector	%	cum
1	26	20.4	41	12.6	12.6	26	11.1	11.1
2	30	18.6	50	10.2	22.8	30	6.5	17.6
3	2	15.0	49	8.8	31.6	1	5.3	22.9
4	22	9.6	55	5.7	37.3	41	3.4	26.3
5	9	7.5	40	5.4	42.7	22	2.7	29.0
6	45	4.8	1	3.5	46.2	45	2.4	31.4

Table 7.2 shows that five sectors account for more than 40% of the production for household consumption. More than a quarter of household energy requirements can be attributed to only four production sectors; these are the basic industries, chemical and metal, agriculture and the trade sector. Considering indirect energy requirements only, about 50% of indirect energy requirements of households takes place in the four sectors mentioned[2]. This

[2] According to table 5.9, the share of indirect energy requirements in total energy requirements of households is 53%.

means that the remaining part is distributed over 49 non-energy sectors. The sectors with a high share in household energy requirements deserve most attention in conservation policy.

Table 7.1 showed the share of each production sector in the energy requirements of the households. Sectors with a high share are relevant in energy conservation policies. For example, a decrease of 1% in the direct energy intensity of the chemical basic products industry results in a decrease of 1913 TJ in household energy requirements, while a decrease of 1% in the direct energy intensity of the sector machinery results in a decrease of only 46 TJ in household energy requirements. So, the order in the sectors with respect to their share in the indirect energy requirements of households determines the ranking for energy conservation measures. However, the energy conservation potentials differ per sector. Appendix B.6 presents data on the technical energy conservation potentials of production and consumption sectors derived from two studies (Melman et al., 1991; Beer et al., 1994)[3]. The technical energy conservation potential of a sector is the reduction of the direct energy use in that sector that can be achieved at a certain moment by implementing the most efficient technology available. Technical energy conservation potentials take into account the expected improvements in technology. The potentials are based on the level of activities in the base year, so volume changes in production or consumption are not taken into account. The TNO-study and ICARUS-study present conservation potentials for both fuel consumption and electricity consumption.

Table 7.3 gives an overview of the savings in household energy requirements and related CO_2 emissions in the year 2015 as a result of the implementation of technical energy conservation potentials from the TNO-study and ICARUS-study. The calculations assume no changes in the 1990 production structure and consumption pattern. E.g. the implementation of technical energy conservation measures in all industrial sectors according to the TNO-study results in a reduction of household energy requirements of 6.1%. This reduction in household energy requirements mainly takes place in industry. A small part takes place in the energy supply system, since less energy has to be converted for industry.

Since the technical energy conservation potentials in the ICARUS-study are more optimistic, the savings according to these study are higher. Due to the technological improvements in the production sectors and savings in the household sector the ICARUS data base results in more than 50% reduction in household energy requirements. Almost half of the savings can be attributed to

[3] In this chapter the first study is referred to as the TNO-study and the second one as the ICARUS-study.

Table 7.3 Savings in household energy requirements (%) and savings in household CO_2 emission (%) as a result of the implementation of technical energy conservation potentials in production and consumption sectors.

sector	TNO		ICARUS	
	energy	CO_2	energy	CO_2
industry	6.1	6.0	9.0	9.1
food	1.1	1.0	1.7	1.5
textiles	0.4	0.3	0.6	0.6
paper	1.2	1.1	1.9	1.7
chemical products	1.4	1.3	1.7	1.7
building materials	0.5	0.5	0.7	0.7
basic metal	0.7	1.0	1.2	1.8
metal products	0.5	0.5	0.8	0.7
other	0.2	0.2	0.4	0.4
agri- and horticulture	3.9	3.4	3.9	3.4
services	6.7	6.4	8.1	7.9
transport[a]	.7	.7	1.0	1.0
households[b]	17.7	16.7	28.0	26.1
subtotal	35.1	33.1	50.0	47.5
energy supply system	4.2	6.3	3.5	5.4
total	39.3	39.4	53.5	52.9

[a] excl. passenger car transport; [b] incl. passenger car transport

the households themselves: more efficient houses, electric appliances and private cars. The other half of the savings is achieved by savings in the production sectors. In contrast to the data given in table 7.2, the savings in agriculture and horticulture are higher than the savings in the basic industries (chemical and metallurgical products) since the technical energy conservation potentials of these basic industries are rather low. This illustrates that not all sectors with a high share in household energy requirements also contain the best options for conservation. Application of the TNO-study results in more savings in the service sectors than in the industry sectors. The ICARUS-study shows the opposite. Total savings range from 40% (according to the TNO data) to 53.5% (according to the ICARUS data).

Table 7.3 also shows the additional effect of measures in the energy supply system on household energy requirements and on household CO_2 emissions. The savings concern the savings in the energy supply system after the implementation of the measures in all other sectors. For both studies, the same measures are implemented in the energy supply system. Since the measures in the other sectors derived from the ICARUS-study result in larger

Table 7.4 Energy requirements of households for the years 1990 and 2015 in PJ allocated to production and consumption sectors.

sector	1990	2015	reduction (%)
non-energy sectors	915.8 (53.1)	496.8 (62.0)	45.7
households	810.3 (46.9)	305.1 (38.0)	62.4
total	1726.1	801.9	53.5

savings, the additional savings in the energy supply system are lower because less energy has to be converted. So, household energy requirements can be lowered by an extra 3-4% through measures in the energy supply system. Total CO_2 emission of households can be lowered by 5-6%. Besides the lowering of energy requirements, the shift to natural gas-based electricity production plays a role in CO_2 emission reduction.

Household energy requirements in 2015 are estimated on the basis of the technical energy conservation potentials from the ICARUS-study[4]. Table 7.4 shows the potential savings in household energy requirements attributed to production sectors and households. Compared to the situation in 1990, total savings in 2015 amount to more than 50%. Since the possible savings in direct energy requirements are higher than those in indirect requirements, the share of indirect energy in household energy requirements becomes even larger than in 1990.

The calculations presented are based on the 1990 situation and do not take into account volume changes in consumption resulting from population growth and growth in purchasing power. According to scenarios like the Balanced Growth scenario of the CPB (1992), the average annual increase in private consumption will be 3.2% in the period 1991-2015. Applying this value to household energy requirements and neglecting further population growth or changes in household membership, the household energy requirements in 2015 will rise to 1509 PJ[5]. If population growth (0.4% annually) is considered too, household energy requirements will rise to 1667 PJ. This means that, despite the implementation of all presently known energy efficiency enhancing technologies, the predicted household energy requirements in 2015 are at the same level as in 1990. In this calculation, no changes in consumption pattern are assumed. Figure 7.1 shows the effect on household energy requirements. The figure also shows the values for the year 2000 based on the conservation

[4] The calculations in the remaining part of this section are illustrated on basis of the ICARUS-data. Calculations based on the TNO-data can be carried out similarly.

[5] An elasticity between energy requirements and spendings of 0.8 is assumed. This elasticity is derived from (Vringer and Blok, 1995).

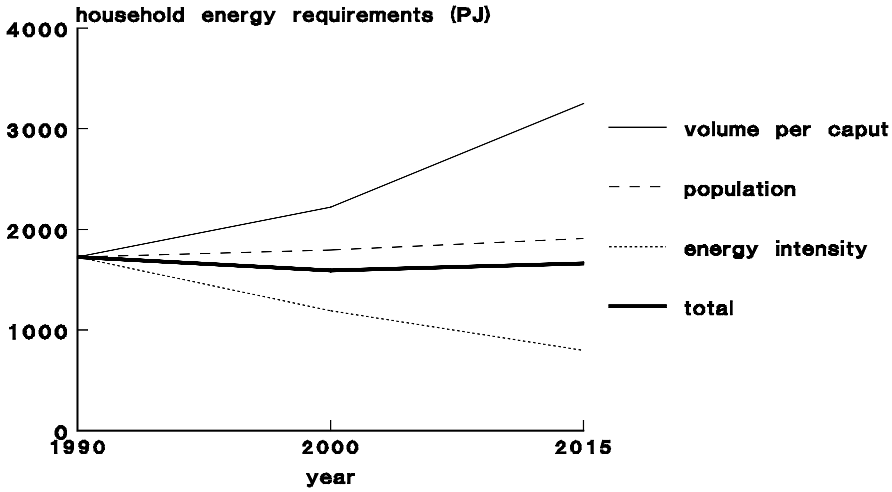

Figure 7.1 Household energy requirements in 2000 and 2015 due to changes in three factors separate and combined. The factors are energy intensity, volume per caput and population.

potentials for 2000 (Beer et al., 1994) and the Balance Growth scenario of the CPB (1992). After 2000, the exponentially increasing private consumption has a larger effect on household energy requirements than the improvements in energy efficiency.

Based on the technical energy conservation potentials of the ICARUS-study total energy intensities of production sectors are calculated. With these energy intensities, the direct and indirect energy flows in the Dutch economy are calculated for the year 2015 (see figure 7.2). No volume changes are taken into account. A comparison of figure 7.2 to figure 5.8 shows that the predicted reduction in the indirect household energy requirements in the period 1990-2015 is 45%. The predicted reduction in the embodied energy of the exports is 33%, so the relative share of the exports in overall domestic production becomes more important.

7.3 EAP SCENARIO STUDIES

The preceding section used the input-output formalism for an assessment of energy reduction potentials. This resulted in the identification of sectors and consumption categories that are the prime candidates for energy reduction programmes. The challenge to identify the specific goods and services within these general categories must be dealt with by other techniques. This issue can

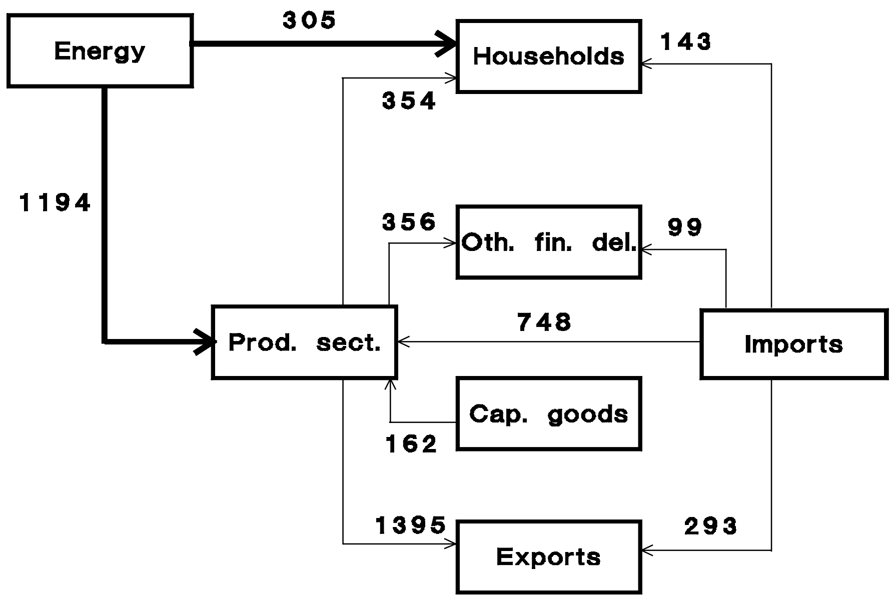

Figure 7.2 Direct and indirect energy flows in the Netherlands in the year 2015 (in PJ).

be studied in detail by modifying the energy intensities of consumption items (see section 5.2). These energy intensities are calculated with the Energy Analysis Program (EAP) described in chapter 4. The key parameters in the EAP database of basic data can be changed. EAP provides thereby the option to study the effect of changes in technology on household energy requirements too. This section describes the possibilities of this method by showing the effect of some conservation options implemented in this way. These examples serve to illustrate the techniques used, and are not intended to exhibit an exhaustive investigation of options.

Only the consumption items which are analysed with EAP are influenced in the proposed approach. About 69% of the indirect energy requirements of households is covered by EAP analyses (see 5.3.3). In the analyses in this section this percentage is enlarged by linking some consumption items that do not have a corresponding analysis in EAP to the energy intensities from other consumption items (e.g. flowers are linked to greenhouse vegetables).

Consumption items require energy in all stages of their life cycle, from

Table 7.5 Distribution of energy requirements (%) over the life cycle of some main consumption categories based on EAP analyses; (1 = basic materials, 2 = production, 3 = transport, 4 = trade, 5 = waste, 6 = total).

category	(1)	(2)	(3)	(4)	(5)	(6)
food	55	25	4	17	-1	100
house	67	16	8	0	8	100
housing	56	24	1	20	-1	100
clothing, etc	34	25	0	41	0	100
hygiene	25	55	0	20	0	100
recreation	42	29	1	31	-4	100
transport	72	32	2	30	-35	100
total	53	25	3	21	-2	100

the production of the basic materials to the waste disposal[6]. Table 7.5 shows the distribution of the energy requirements over the life cycle stages for some main consumption categories. The calculations only concern the part of the indirect energy requirements of households that is based on EAP analyses. Table 7.5 shows that 95% of the indirect energy requirement of households, as analysed by EAP, takes place in the stages basic materials, production and trade. Therefore, these stages are relevant for the study of energy reduction potentials. The basic data belonging to these stages form the prime target for further investigations. For example, if the energy efficiency in all trade sectors increases by 10%, the indirect energy requirements of households decrease by 2%. More detailed information can of course be derived from corresponding analyses at subcategories within the main categories given in table 7.5.

In order to illustrate the method of implementing energy conservation measures in the EAP model, the effects of two specific conservation options on the indirect energy requirements are presented here:

- The first option concerns the assumption that there is no greenhouse horticulture and that all vegetables, fruit and flowers are grown in the field. This option results in lower energy requirements for the categories food and housing. The over-all decrease of the indirect energy requirement is almost 7%.
- The second option is a decrease of the embodied energy of aluminum from almost 200 MJ per kilogram to 20 MJ per kilogram. This target can be achieved if all aluminum is recycled. The over-all decrease in the indirect energy requirements as a consequence of this second option is 1%. Categories that show lower energy requirements are household

6 The energy requirements in the waste disposal stage may be negative as a result of recycling or waste incineration.

effects, house and recreation.

7.4 CONCLUSIONS

This chapter describes investigations into options for reduction in household energy requirements and CO_2 emissions by selective changes in the energy efficiency of production and consumption sectors. The identification of the relevant actors and processes is not trivial: some sectors contribute significantly to the overall energy requirements of a certain good or service, but the conservation potential is marginal, or vice versa. This chapter describes a methodology that aims at resolving this problem, and that can identify the relevant actors and processes that require prime attention in energy efficiency enhancement or conservation programmes. This turns out to be a three-step procedure:

1) identification of relevant economic sectors,
2) assessment of the reduction potential of these sectors, followed by a ranking procedure of the reduction potentials,
3) detailed EAP-based analyses of goods and services that make use of contributions from the categories identified in step 2.

A full quantification of the impacts of this approach is beyond the scope of this study, and requires further refinement of methodology and applications. Illustrative examples show a reduction potential of 40-55% of the 1990 household energy requirements. Such potential gains will be offset completely if private consumption growth continues along the lines of the last 40 years.

APPENDIX 7.A: SENSITIVITY ANALYSIS

Sensitivity analysis is used to investigate for each element of the parameters of a model the effect of a variation in that element on the model outcomes. In this way, the important elements of the model parameters can be determined. Important elements are elements with a large effect on the outcomes. Sensitivity analyses have been performed before in economic input-output analysis (Sebald, 1974; Viet, 1980). These analyses concerned the effect of changes in one element of the technological matrix on the Leontief inverse matrix and total production. Van der Linden en Oosterhaven (1995) investigated changes in columns of the technological matrix corresponding with technological change.

Viet (1980) compared two methods of sensitivity analysis: the Sebald method and the Sekulic method. The first method is also described extensively in Sebald (1974). In both methods, an element in the technological matrix A is changed, and the effect on the Leontief inverse B is determined. The elements of the new inverse are calculated directly from the elements of the original inverse. Viet demonstrated mathematically that both methods are equal. Both methods differ in the way in which they identify the important elements. Furthermore, Sekulic investigated the effect of the variation in an element of the technological matrix on the total production vector.

In this appendix, the methods presented in the economic literature are applied to energy intensities and energy requirements. Sensitivity analysis can be used in the search for options to realize an optimal reduction in energy requirements and the corresponding CO_2 emissions. Sensitivity analysis enables the consideration of the effects of changes in the production structure or energy efficiency of a certain sector on household energy requirements. This appendix investigates first the effect of changes in the technological matrix. After that, changes in the direct energy intensity vector are investigated. Formula (3.15) is used for the investigations of the effect on the energy intensities. The effect on household energy requirements are analysed on the basis of formula (3.29).

7.A.1 Changes in the technological matrix

This section investigates the changes in one element of the technological matrix on energy intensities and household energy requirements. For element A_{ij} of the technological matrix a deviation ϕ is assumed[7]. The other elements of A remain unchanged. The matrix A^n is defined as:

$$A^n = A + F \qquad (7.A.1)$$

All elements of F are zero except F_{ij} is equal to ϕ. Based on the new technological matrix A^n, the changes in the energy intensity vector are determined under the assumption that the direct energy intensities remain unchanged. The notation for the change in the energy intensities as a result of the change in A_{ij} is h^{ij}. So, h^{ij} is defined as:

$$h^{ij} = e^n - e \qquad (7.A.2)$$

Viet (1980) gives a derivation for the change in total production as a result of the change in the technological matrix. Similarly, Wilting and Biesiot (1993) derived a formula for the change in energy intensities, h. This formula is:

[7] Derivations are carried out for positive changes. Derivations for negative values are treated analogously.

$$h_k^{ij} = \frac{e_i \; F_{ij} \; B_{jk}}{1 - F_{ij} \; B_{ji}}, \qquad \forall \; k = 1, .., n \tag{7.A.3}$$

The calculation of the changes in the energy intensities only needs the energy intensity vector, e, and the Leontief inverse matrix, $B = (I\text{-}A)^{-1}$, The formula is very practical, since only one matrix has to be inverted.

Formula (7.A.3) gives the effect of a change in an element of the technological matrix on the energy intensity vector. Similarly, the effect on household energy requirements can be determined:

$$\Delta^{ij} = \sum_{k=1}^{n} h_k^{ij} \; y_k \tag{7.A.4}$$

with Δ^{ij} the total change in household energy requirements as a result of the change in element A_{ij} of the technological matrix. For each element of the technological matrix the effect on household energy requirements can be calculated. In this way, the importance of each element of the technological matrix can be determined.

The sensitivity analysis is illustrated using example 3.2.2. A change of 10% is assumed in element A^{11}. Formula (7.A.4) determines the changes in the energy intensities, h^{11}. Matrix F and h^{11} are:

$$F = \begin{bmatrix} 1/40 & 0 \\ 0 & 0 \end{bmatrix}, \qquad h^{11} = \begin{bmatrix} 2/15 \\ 1/15 \end{bmatrix}$$

Since element A_{11} in the technological matrix is increased, household energy requirements are increased too. The increase is:

$$\Delta^{11} = h^{T} \; y = \begin{bmatrix} 2/15 & 1/15 \end{bmatrix} \begin{bmatrix} 20 \\ 10 \end{bmatrix} = 10/3$$

Similarly, the effects of changes in the other elements of the technological matrix on the energy intensities and household energy requirements can be calculated. These are (assuming 10% changes):

$$h^{12} = \begin{bmatrix} 32/490 \\ 96/490 \end{bmatrix}, \qquad \Delta^{12} = 1600/490$$

$$h^{21} = \begin{bmatrix} 32/490 \\ 16/490 \end{bmatrix}, \qquad \Delta^{21} = 800/490$$

Since element A_{22} is zero, the effects of changes in this element are not considered.

7.A.2 Identification of important parameters

The next step is the determination of those elements in the technological matrix for which changes have the most effect on the energy intensities and household energy requirements. Sebald investigated the effect of changes in the technological matrix on the Leontief inverse matrix[8]. Sebald calculated for a specific change in element A_{ij} of the technological matrix all changes in the Leontief inverse matrix B. Sebald defined A_{ij} as important compared to element B_{kl} of B in case the change in A_{ij} effects at least a certain percentage change in B_{kl}. The importance of element A_{ij} is determined by counting the elements of B for which A_{ij} is important. Most important are those elements of A which are most often important compared to the elements of B.

Sekulic determined the most important elements differently. He started from the opposite: how much may an element change at most, so that no element of the total production vector changes with more than a fixed percentage. This section applies Sekulic' analysis to the energy analysis. The question is then: how much is an element of the technological matrix allowed to change at most, so that no element of the energy intensity vector changes with more than a fixed percentage.

By using formula (7.A.3), a formula is derived for the deviation F_{ij} in element A_{ij} of the technological matrix given a change h_k in energy intensity e_k. This formula is:

$$F_{ij} = \frac{h_k}{e_i \; B_{jk} + h_k \; B_{ji}} , \qquad \forall \; i, j = 1, .., n \tag{7.A.5}$$

In the example, a change of 10% (= 16/50) in energy intensity e_1 can be achieved by one of the following changes in the technological matrix:

8 Sebald called this the 'Most Important Parameter' (MIP) problem.

$F_{11} = 5/88, \ F_{12} = 5/22, \ F_{21} = 5/44, \ F_{22} = 5/16.$

For each energy intensity, the corresponding changes in the elements of the technological matrix can be determined. The next step is the determination of the maximum percentage R_{ij} with which element A_{ij} may change, so that no energy intensity changes with more than a fixed percentage ρ. The following formula[9] determines R_{ij}:

$$R_{ij}\ (\rho) = \frac{100\ \rho}{A_{ij}\ (\ 100\ e_i\ \max\limits_{k}\ B_{jk}/e_k\ +\ \rho\ B_{ji}\ )} \tag{7.A.6}$$

High values of R_{ij} indicate less important elements A_{ij}. With this formula, it is possible to order the elements of A for a given percentage deviation ρ. The importance of elements can also be indicated with a visual representation of matrix R. Sekulic assumes one fixed value for ρ for all energy intensities. Viet also analyses other values for ρ. For the example, matrix R (with ρ is 10%) is:

$$R = \begin{bmatrix} 500/22 & 500/61 \\ 500/11 & 0 \end{bmatrix}$$

Element A_{12} of the technological matrix is the most important. If no energy intensity is allowed to change with more than 10%, A_{12} is not allowed to change by more than 500/61%.

7.A.3 Changes in the direct energy intensity vector

Until now, the discussion concerned the effect of changes in the technological matrix on the energy intensities. The next step concerns the effect of changes in direct energy intensities on the (total) energy intensities. Starting point is again formula (3.15). For one element of the direct energy intensity vector, d_i, a deviation ϕ is assumed. The other elements of d remain unchanged. Analogously to formula (7.A.1), d^n is defined as:

$$d^n = d + f \tag{7.A.7}$$

with f_i is ϕ and the other elements of f are equal to zero. The changes in the energy intensities are determined under the assumption that the technological matrix remains unchanged. The change h^i in the energy intensities is defined as:

9 Wilting and Biesiot (1993) give a derivation for this formula.

$$h^i = e^n - e \tag{7.A.8}$$

The change in the energy intensity of sector k as a result of a change in the direct energy intensity of sector i is:

$$h_k^i = f_i \ B_{ik} \ , \qquad \forall \ k = 1, .., n \tag{7.A.9}$$

The effect on household energy requirements is analogous to formula (7.A.4):

$$\Delta^i = \sum_{k=1}^{n} h_k^i \ y_k \tag{7.A.10}$$

with Δ^i the total change in household energy requirements as a result of the change in element d_i of the direct energy intensity vector.

Similarly as above in the case of the elements of the technological matrix, an order of importance can be determined for the elements of the direct energy intensity vector. It is assumed again that no energy intensity may change more than a fixed percentage (ρ). For each element of the direct energy intensity vector the permitted percentage deviation is derived. First, f_i is derived as a function of h_k:

$$f_i = \frac{h_k}{B_{ik}} \ , \qquad \forall \ i = 1, .., n \tag{7.A.11}$$

The next step is the determination of the vector r which gives for each element of the direct energy intensity vector the percentage deviation, so that for all energy intensities the percentage deviation is less than or equal to ρ. The formula for the determination of the elements of r, which is derived in (Wilting and Biesiot, 1993), is:

$$r_i \ (\rho) = \frac{\rho}{d_i \ \max\limits_{k} \ B_{ik}/e_k} \tag{7.A.12}$$

Elements of the direct energy intensity vector with a small r-value are more important than elements with a high r-value. The permitted percentage change is r_i, so that no element of the energy intensity vector changes with more than ρ%.

7.A.4 Calculations for the year 1990

This section shows the application of the model in formula (7.A.4) on the 1990 household energy requirements in the Netherlands. Wilting and Biesiot (1993) applied the models discussed in this appendix more extensively to the energy intensities of production sectors and household energy requirements in 1987.

Figure 7.A.1 shows a visual representation of the effect of a 10% change in the elements of the technological matrix on household energy requirements in the Netherlands in 1990[10]. The black elements are most important: a 10% change in each element separately increases household energy requirements with more than 28 TJ. Elements with a high value generally are more important. This is in line with the results for 1987 in (Wilting and Biesiot, 1993).

This appendix does not show the effect of changes in elements of the direct energy intensity vector on household energy requirements according to formula (7.A.10). This effect was already treated (more pragmatically) in section 7.1 of this study.

[10] Zero elements in the technological matrix are not considered. These elements are depicted white in figure 7.A.1.

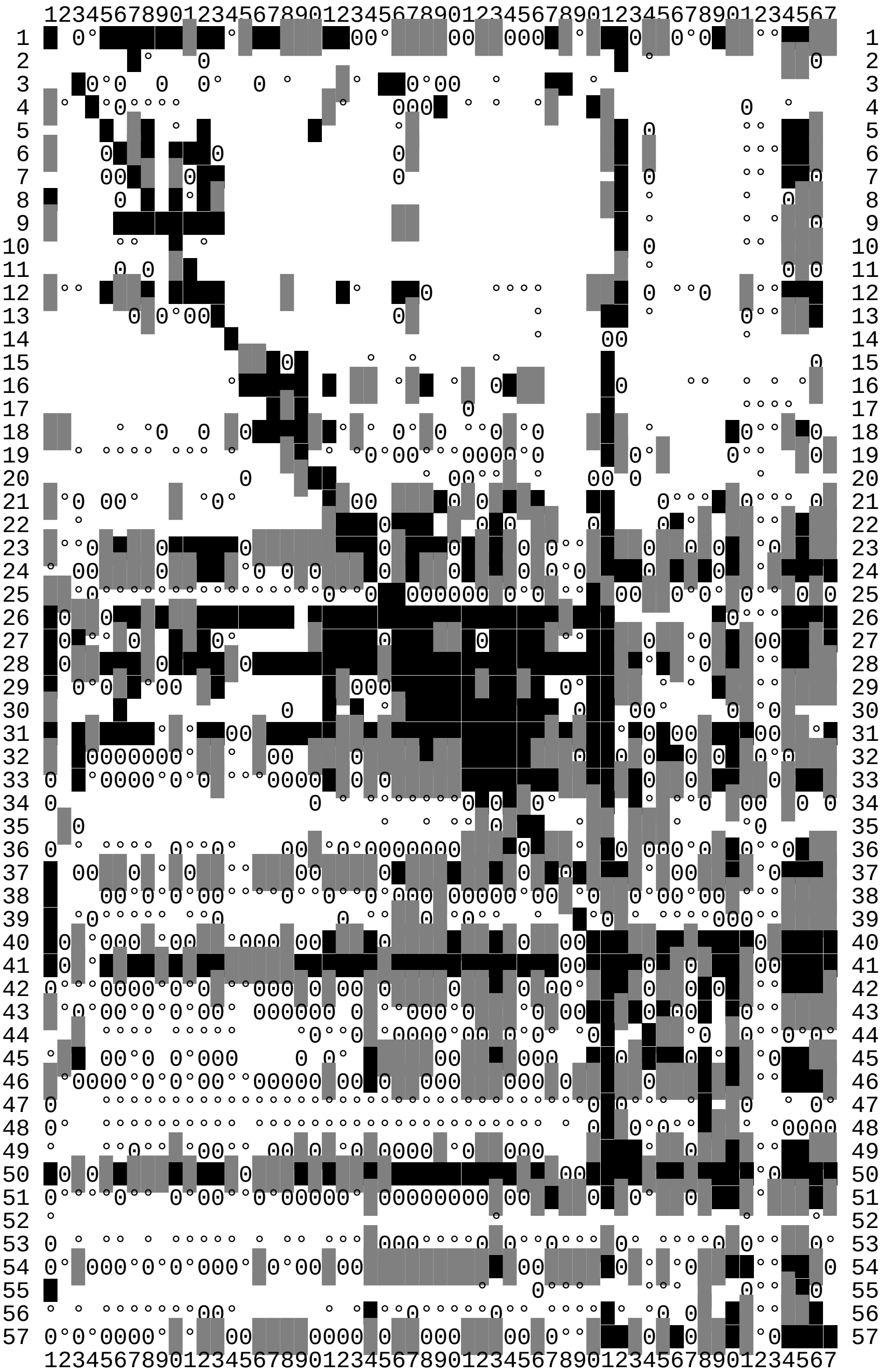

Figure 7.A.1 Visual representation of the effect in TJ of 10% changes in the elements of the technological matrix on household energy requirements.
(°: < 1.385; 0: 1.385 - 5.924; ▒: 5.924 - 28.117; █: > 28.117)